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Yamarthi et al.

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(54) **AIRFOIL ASSEMBLY WITH AN INTERNAL REINFORCEMENT STRUCTURE**

(71) Applicant: **General Electric Company**, Schenectady, NY (US)

(72) Inventors: **David Raju Yamarthi**, Bengaluru (IN); **Vasanth Kumar Balaramudu**, Bengaluru (IN); **Vishnu Vardhan Venkata Tatiparthi**, Bengaluru (IN); **Paul Mathew**, Bengaluru (IN); **Douglas Lorrimer Armstrong**, Needham, MA (US); **Gary Willard Bryant, Jr.**, Loveland, OH (US); **Nuthi Srinivas**, Bengaluru (IN)

(73) Assignee: **General Electric Company**, Schenectady, NY (US)

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F01D 5/28 (2006.01)

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CPC ***F01D 5/147*** (2013.01); ***F01D 5/282*** (2013.01); *F05D 2240/30* (2013.01); *F05D 2250/25* (2013.01); *F05D 2300/6034* (2013.01); *F05D 2300/612* (2013.01)

(58) **Field of Classification Search**
CPC F01D 5/147; F05D 2250/25
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,248,221	A	7/1941	Dornier	
2,458,975	A	1/1949	Brady	
5,269,657	A	12/1993	Garfinkle	
5,279,892	A	1/1994	Baldwin et al.	
8,038,408	B2	10/2011	McMillan	
8,251,660	B1 *	8/2012	Liang	F01D 5/187 415/115
9,957,972	B2 *	5/2018	Foster	F01D 5/282
2016/0032939	A1	2/2016	Anderson et al.	
2016/0222793	A1 *	8/2016	Snyder	F01D 9/065
2019/0145269	A1	5/2019	Campbell	

FOREIGN PATENT DOCUMENTS

FR	591117	A	6/1925
FR	719239	A	2/1932

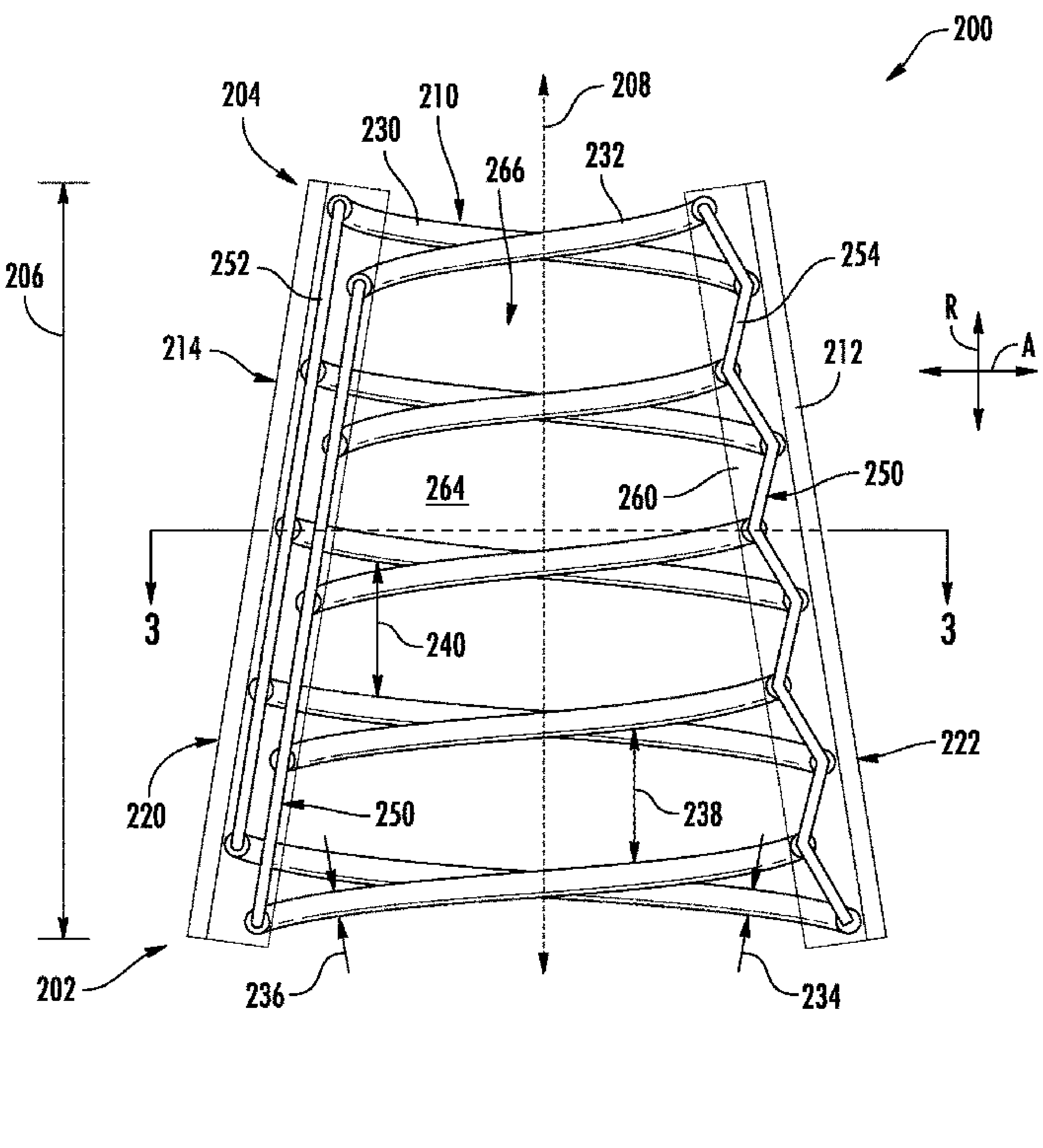
* cited by examiner

Primary Examiner — Michael L Sehn
(74) *Attorney, Agent, or Firm* — Dority & Manning, P.A.

(57) **ABSTRACT**

An airfoil assembly and a method of manufacturing the same are provided, the airfoil assembly defining a span axis, a root end, and a tip end. The airfoil assembly includes a reinforcement structure comprising a first helical support structure wrapped around the span axis between the root end and the tip end and a second helical support structure wrapped around the span axis between the root end and the tip end; a polymeric matrix material positioned at least partially around the reinforcement structure; and an outer skin positioned around the reinforcement structure and the polymeric matrix material.

20 Claims, 5 Drawing Sheets



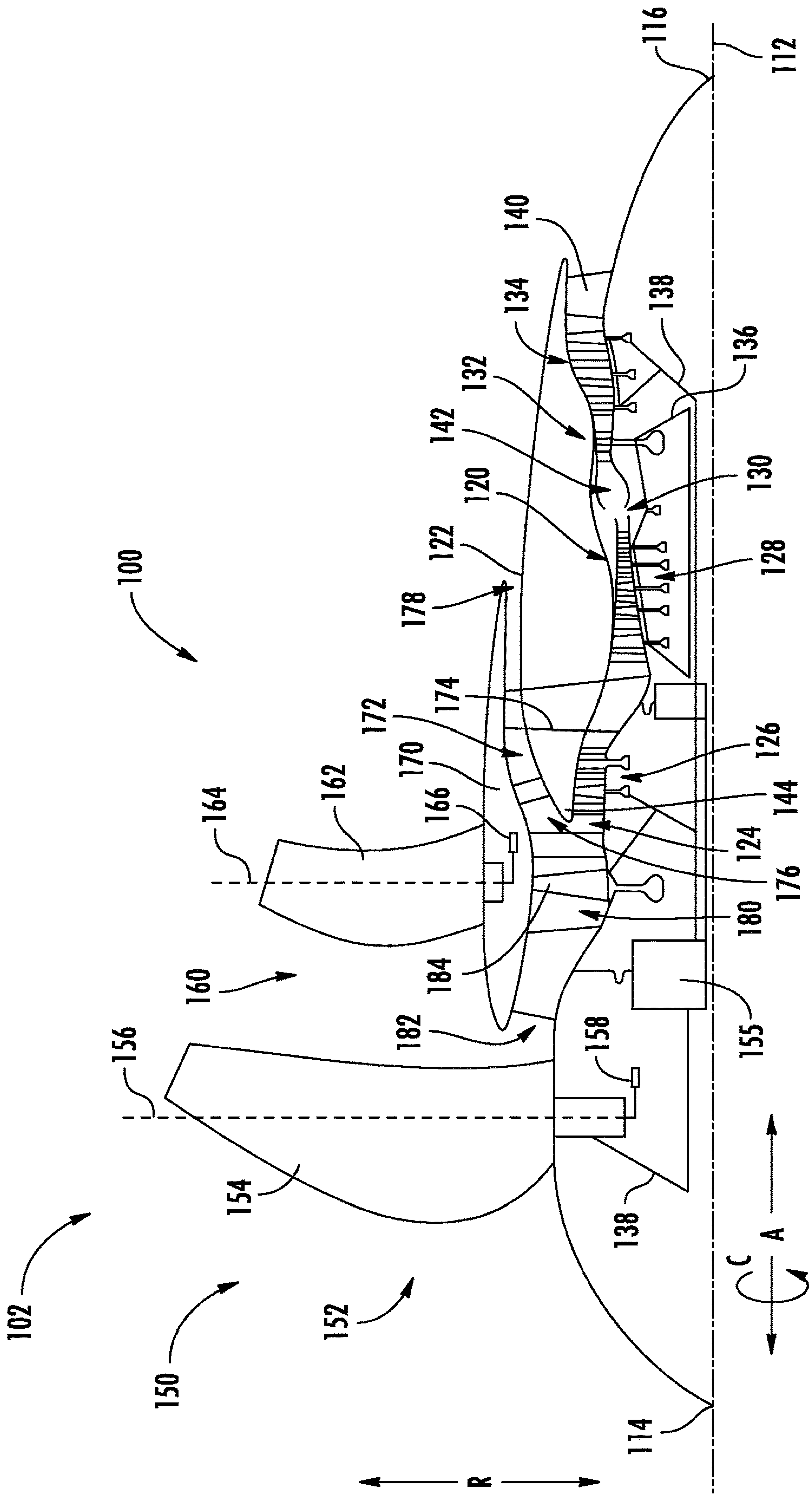

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FIG. 1

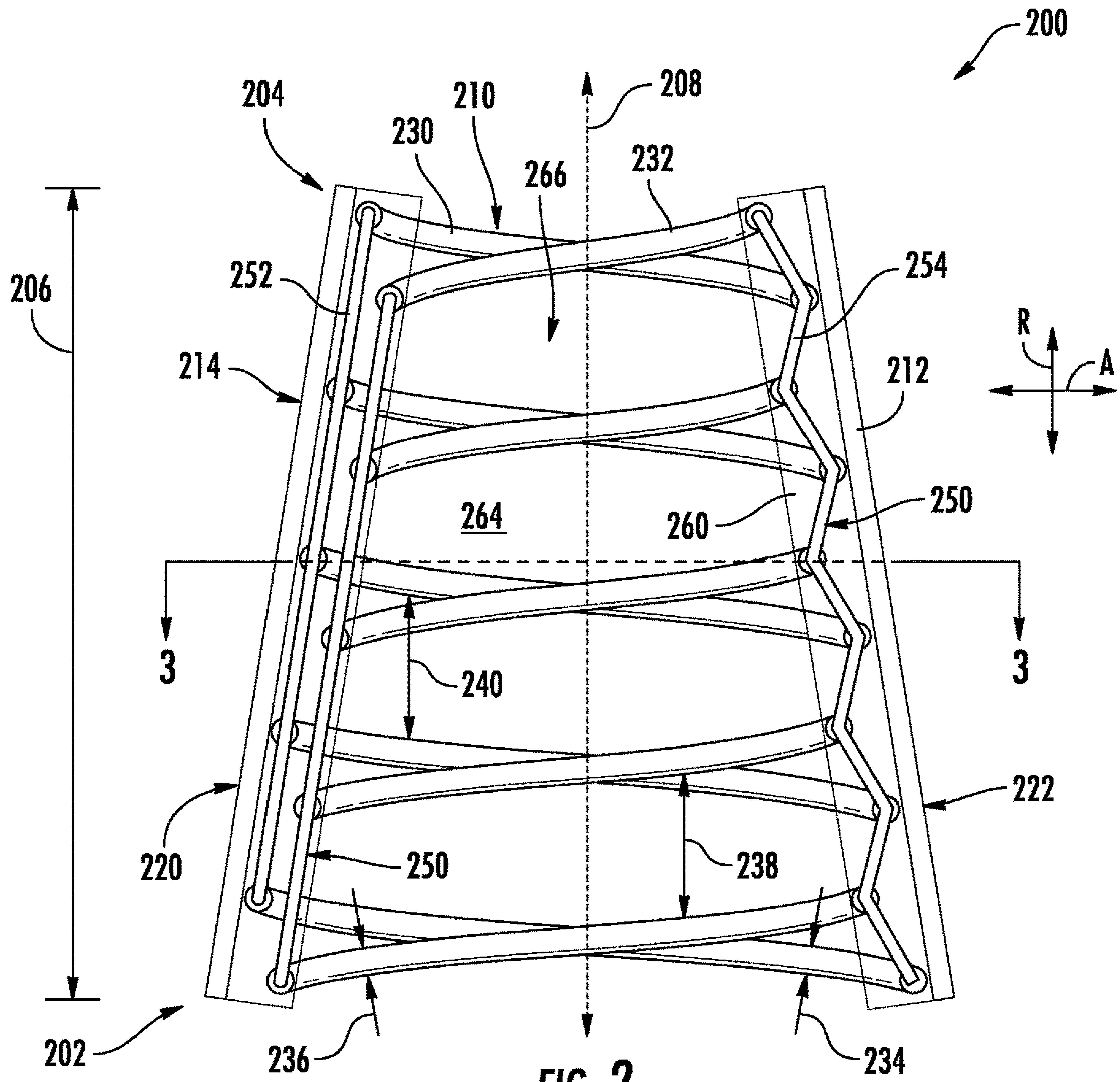
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FIG. 2

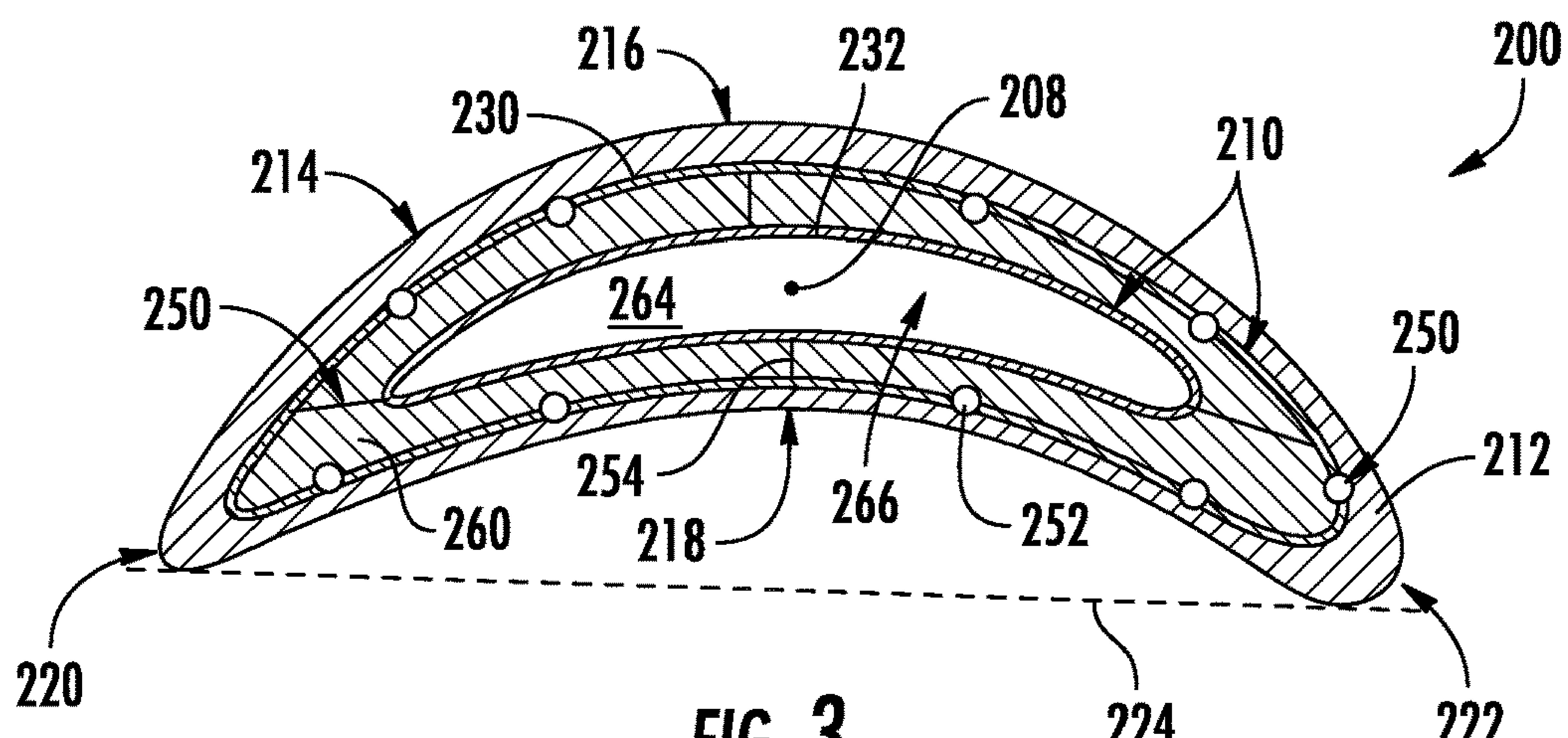
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FIG. 3

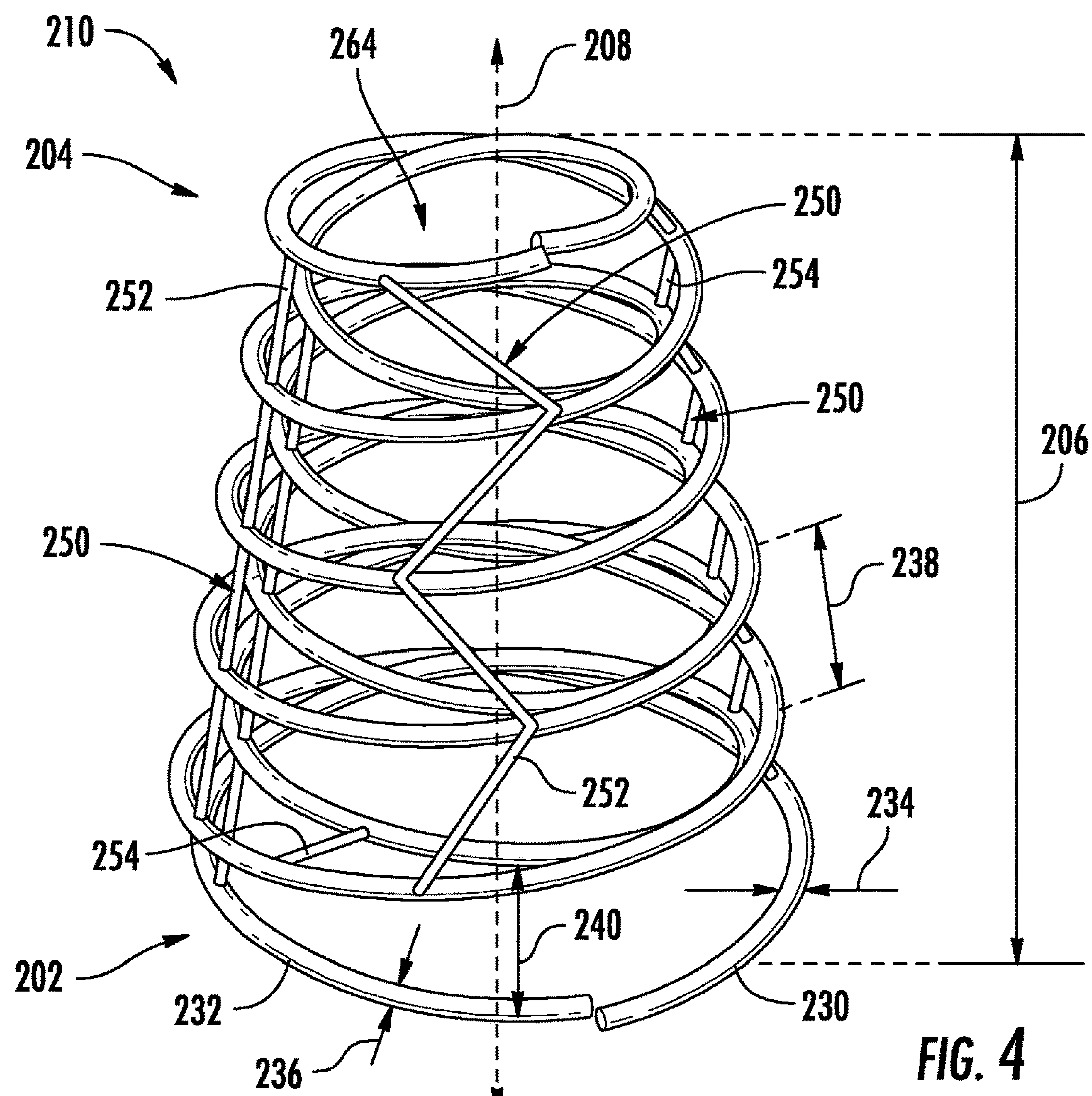
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FIG. 4

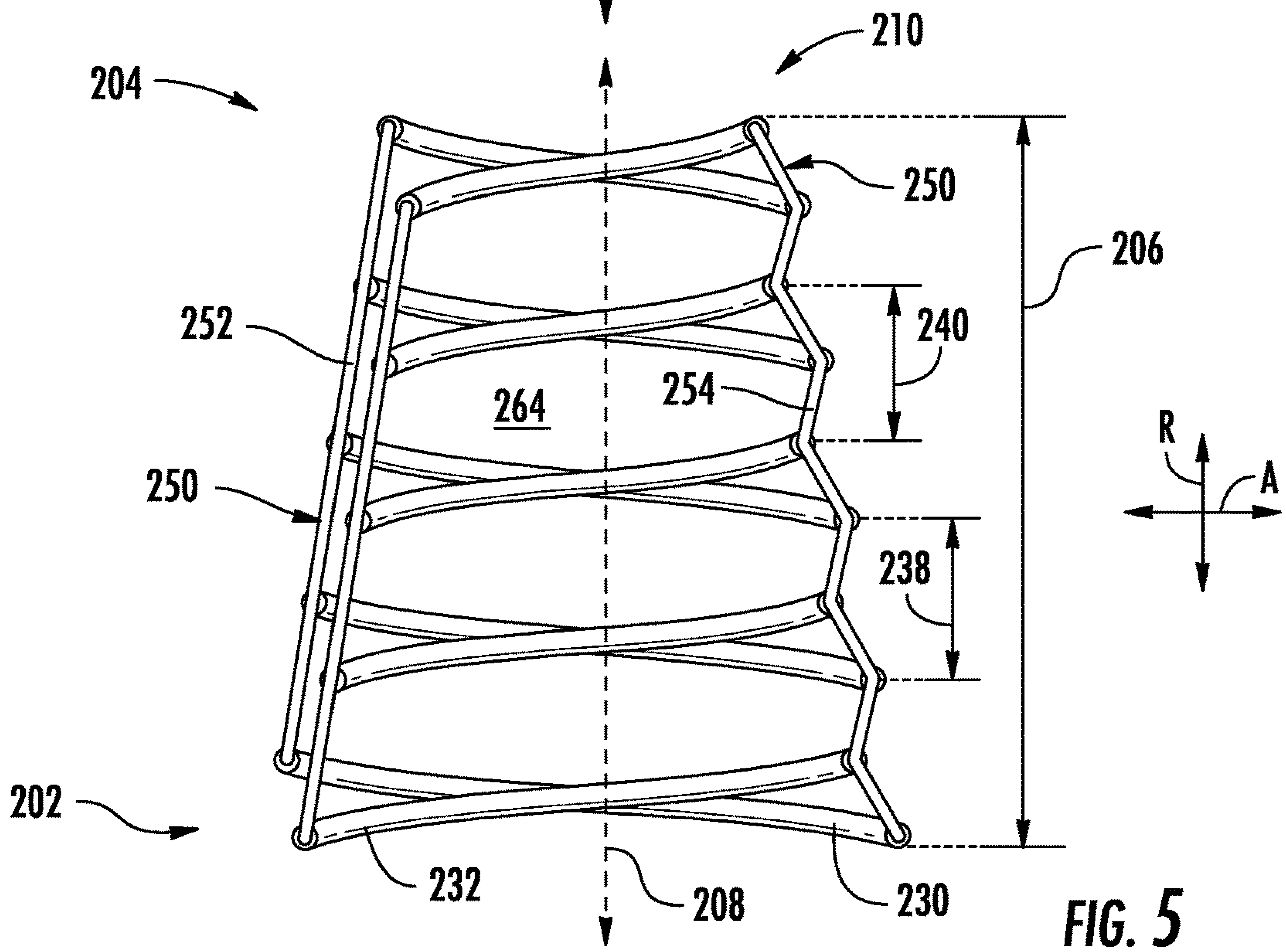
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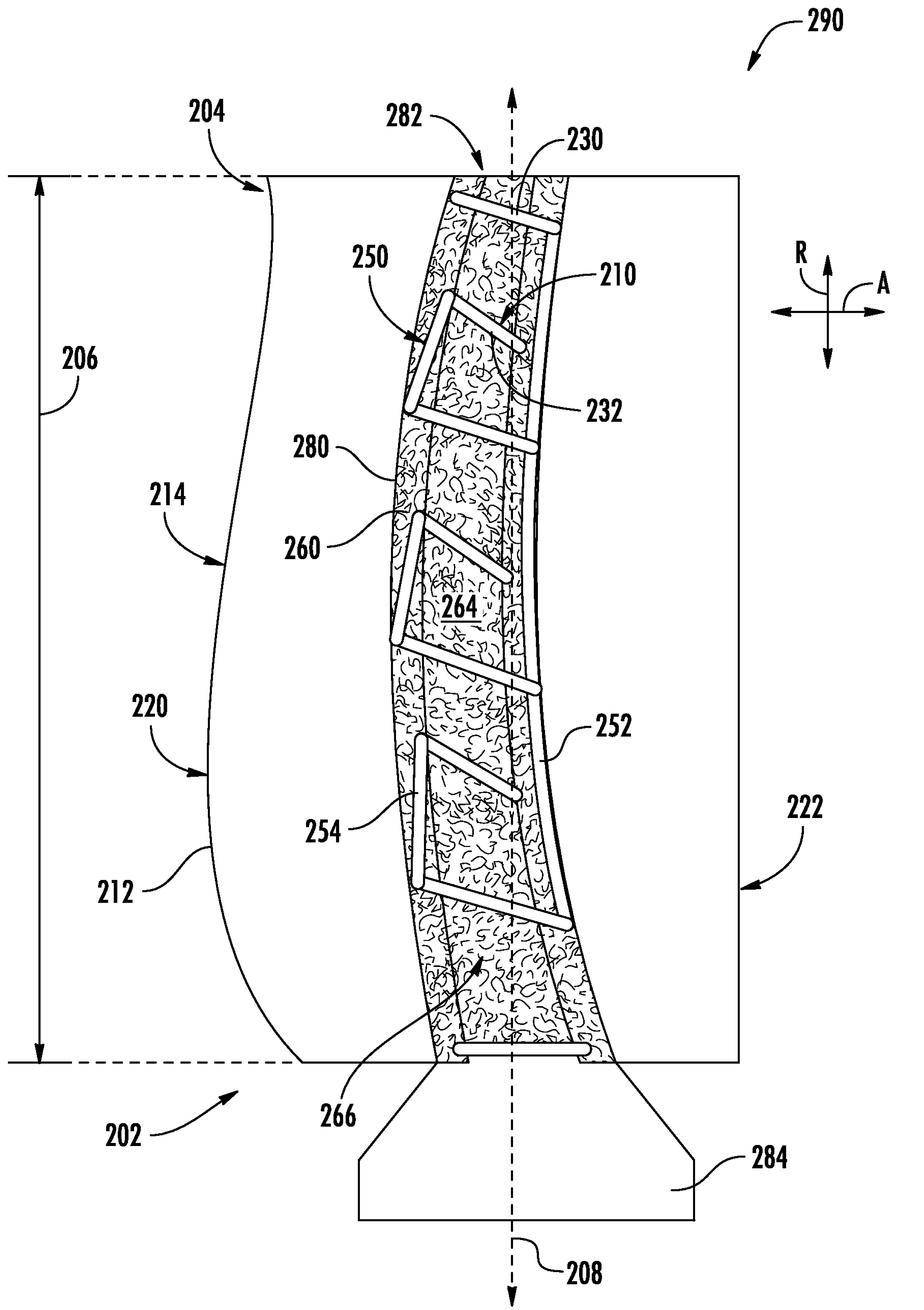
FIG. 5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204
282
230
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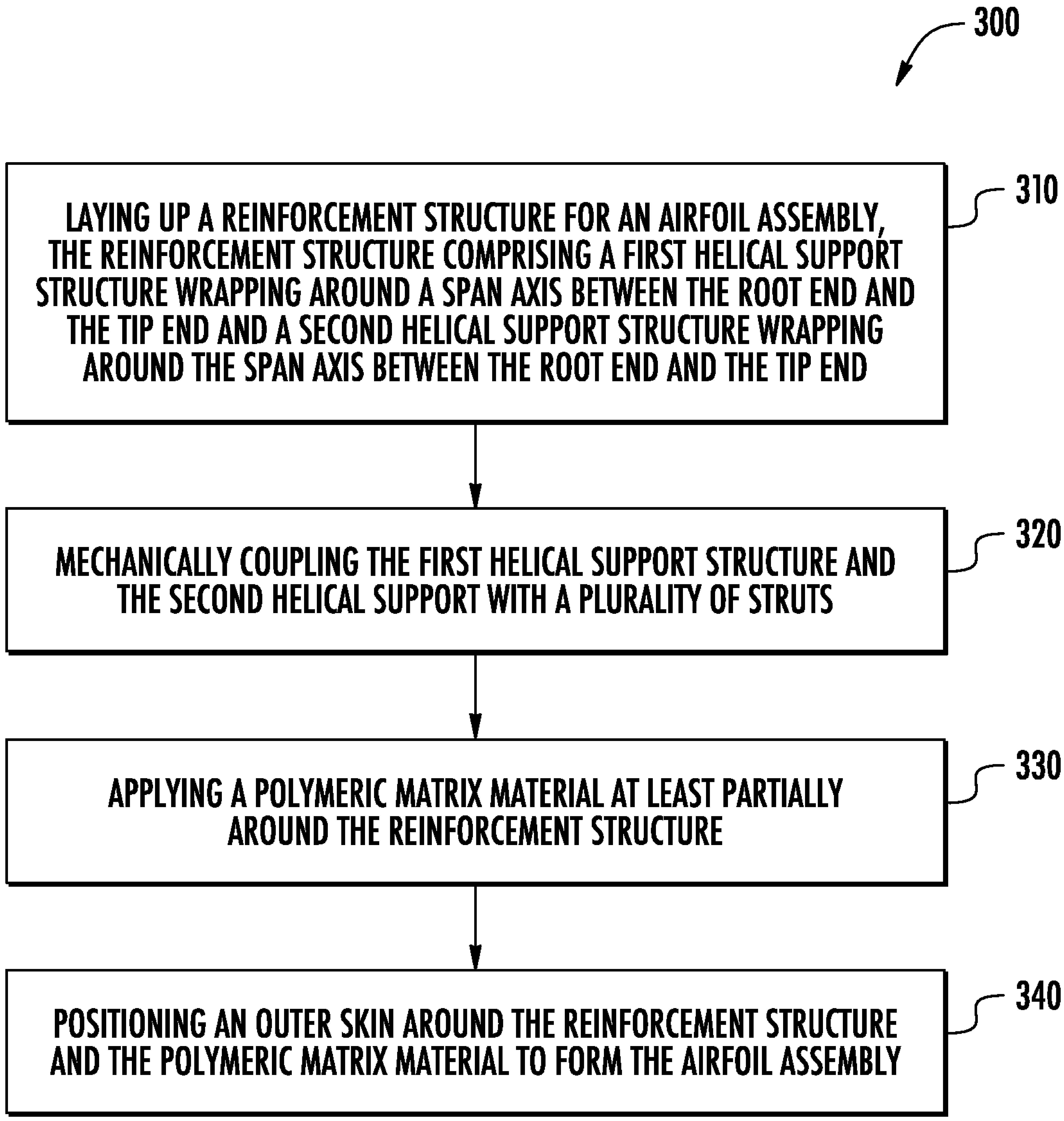
212
266
202
284
208

FIG. 6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LAYING UP A REINFORCEMENT STRUCTURE FOR AN AIRFOIL ASSEMBLY, THE REINFORCEMENT STRUCTURE COMPRISING A FIRST HELICAL SUPPORT STRUCTURE WRAPPING AROUND A SPAN AXIS BETWEEN THE ROOT END AND THE TIP END AND A SECOND HELICAL SUPPORT STRUCTURE WRAPPING AROUND THE SPAN AXIS BETWEEN THE ROOT END AND THE TIP END
310
MECHANICALLY COUPLING THE FIRST HELICAL SUPPORT STRUCTURE AND THE SECOND HELICAL SUPPORT WITH A PLURALITY OF STRUTS
320
APPLYING A POLYMERIC MATRIX MATERIAL AT LEAST PARTIALLY AROUND THE REINFORCEMENT STRUCTURE
330
POSITIONING AN OUTER SKIN AROUND THE REINFORCEMENT STRUCTURE AND THE POLYMERIC MATRIX MATERIAL TO FORM THE AIRFOIL ASSEMBLY
340

FIG. 7

AIRFOIL ASSEMBLY WITH AN INTERNAL REINFORCEMENT STRUCTURE

FIELD

The present disclosure relates to gas turbine engines, and more particularly, to airfoil assemblies and methods for manufacturing the same.

BACKGROUND

A gas turbine engine typically includes a fan assembly and a turbomachine. The turbomachine generally includes an inlet, one or more compressors, a combustor, and at least one turbine. The compressors compress air which is channeled to the combustor where it is mixed with fuel. The mixture is then ignited for generating hot combustion gases. The combustion gases are channeled to the turbine(s) which extracts energy from the combustion gases for powering the compressor(s), as well as for producing useful work to propel an aircraft in flight or to power a load, such as an electrical generator. In a turbofan engine, the fan assembly generally includes a fan having a plurality of airfoils or fan blades extending radially outwardly from a central hub and/or a disk. During certain operations, the fan blades provide an airflow into the turbomachine and over the turbomachine to generate thrust.

BRIEF DESCRIPTION OF THE DRAWINGS

A full and enabling disclosure of the present disclosure, including the best mode thereof, directed to one of ordinary skill in the art, is set forth in the specification, which makes reference to the appended figures.

FIG. **1** is a schematic cross-sectional view of a gas turbine engine in accordance with an exemplary embodiment of the present disclosure.

FIG. **2** is a schematic cross-sectional view of an airfoil assembly that may be used with the exemplary gas turbine engine of FIG. **1** in accordance with an exemplary embodiment of the present disclosure.

FIG. **3** is another schematic cross-sectional view of the exemplary airfoil assembly of FIG. **2** taken along Line **3-3** in FIG. **2** in accordance with an exemplary embodiment of the present disclosure.

FIG. **4** is a partial perspective view of the exemplary airfoil assembly of FIG. **2** in accordance with an exemplary embodiment of the present disclosure.

FIG. **5** is a partial perspective cross-sectional view of the exemplary airfoil assembly of FIG. **2** in accordance with an exemplary embodiment of the present disclosure.

FIG. **6** is a schematic cross-sectional view of an airfoil assembly that may be used with the exemplary gas turbine engine of FIG. **1** in accordance with an exemplary embodiment of the present disclosure.

FIG. **7** provides a flowchart diagram of an exemplary method of manufacturing an airfoil assembly in accordance with an exemplary embodiment of the present disclosure.

DETAILED DESCRIPTION

Reference will now be made in detail to present embodiments of the disclosure, one or more examples of which are illustrated in the accompanying drawings. The detailed description uses numerical and letter designations to refer to features in the drawings. Like or similar designations in the drawings and description have been used to refer to like or similar parts of the disclosure.

As used herein, the terms "first," "second," and "third" may be used interchangeably to distinguish one component from another and are not intended to signify location or importance of the individual components. The terms "includes" and "including" are intended to be inclusive in a manner similar to the term "comprising." Similarly, the term "or" is generally intended to be inclusive (i.e., "A or B" is intended to mean "A or B or both"). The term "at least one of" in the context of, e.g., "at least one of A, B, and C" refers to only A, only B, only C, or any combination of A, B, and C. In addition, here and throughout the specification and claims, range limitations may be combined and/or interchanged. Such ranges are identified and include all the sub-ranges contained therein unless context or language indicates otherwise. For example, all ranges disclosed herein are inclusive of the endpoints, and the endpoints are independently combinable with each other. The singular forms "a," "an," and "the" include plural references unless the context clearly dictates otherwise.

Approximating language, as used herein throughout the specification and claims, may be applied to modify any quantitative representation that could permissibly vary without resulting in a change in the basic function to which it is related. Accordingly, a value modified by a term or terms, such as "generally," "about," "approximately," and "substantially," are not to be limited to the precise value specified. In at least some instances, the approximating language may correspond to the precision of an instrument for measuring the value, or the precision of the methods or machines for constructing or manufacturing the components and/or systems. For example, the approximating language may refer to being within a 10 percent margin, i.e., including values within ten percent greater or less than the stated value. In this regard, for example, when used in the context of an angle or direction, such terms include within ten degrees greater or less than the stated angle or direction.

The word "exemplary" is used herein to mean "serving as an example, instance, or illustration." In addition, references to "an embodiment" or "one embodiment" does not necessarily refer to the same embodiment, although it may. Any implementation described herein as "exemplary" or "an embodiment" is not necessarily to be construed as preferred or advantageous over other implementations. Moreover, each example is provided by way of explanation of the disclosure, not limitation of the disclosure. In fact, it will be apparent to those skilled in the art that various modifications and variations can be made in the present disclosure without departing from the scope of the disclosure. For instance, features illustrated or described as part of one embodiment can be used with another embodiment to yield a still further embodiment. Thus, it is intended that the present disclosure covers such modifications and variations as come within the scope of the appended claims and their equivalents.

The terms "forward" and "aft" refer to relative positions within a gas turbine engine or vehicle, and refer to the normal operational attitude of the gas turbine engine or vehicle. For example, with regard to a gas turbine engine, forward refers to a position closer to an engine inlet and aft refers to a position closer to an engine nozzle or exhaust. The terms "upstream" and "downstream" refer to the relative direction with respect to fluid flow in a fluid pathway. For example, "upstream" refers to the direction from which the fluid flows, and "downstream" refers to the direction to which the fluid flows.

As used herein, the term “first stream” or “free stream” refers to a stream that flows outside of the engine inlet and over a fan, which is unducted. Furthermore, the first stream is a stream of air that is free stream air. As used herein, the term “second stream” refers to a stream that flows through the engine inlet and the ducted fan and also travels through the core inlet and the core duct. As used herein, the term “third stream” or “mid-fan stream” refers to a stream that flows through an engine inlet and a ducted fan but does not travel through a core inlet and a core duct. Furthermore, the third stream is a stream of air that takes inlet air as opposed to free stream air. The third stream goes through at least one stage of the turbomachine, e.g., the ducted fan.

Thus, a third stream means a non-primary air stream capable of increasing fluid energy to produce a minority of total propulsion system thrust. A pressure ratio of the third stream is higher than that of the primary propulsion stream (e.g., a bypass or propeller driven propulsion stream). The thrust may be produced through a dedicated nozzle or through mixing of an airflow through the third stream with a primary propulsion stream or a core air stream, e.g., into a common nozzle.

In certain exemplary embodiments an operating temperature of the airflow through the third stream may be less than a maximum compressor discharge temperature for the engine, and more specifically may be less than 350 degrees Fahrenheit (such as less than 300 degrees Fahrenheit, such as less than 250 degrees Fahrenheit, such as less than 200 degrees Fahrenheit, and at least as great as an ambient temperature). In certain exemplary embodiments, these operating temperatures may facilitate heat transfer to or from the airflow through the third stream and a separate fluid stream. Further, in certain exemplary embodiments, the airflow through the third stream may contribute less than 50% of the total engine thrust (and at least, e.g., 2% of the total engine thrust) at a takeoff condition, or more particularly while operating at a rated takeoff power at sea level, static flight speed, 86 degrees Fahrenheit ambient temperature operating conditions. In other exemplary embodiments, it is contemplated that the airflow through the third stream may contribute greater than 50% of the total engine thrust (and at least, e.g., 2% of the total engine thrust) at an engine operating condition. In other exemplary embodiments, it is contemplated that the airflow through the third stream may contribute approximately 50% of the total engine thrust (and at least, e.g., 2% of the total engine thrust) at an engine operating condition.

Furthermore in certain exemplary embodiments, aspects of the airflow through the third stream (e.g., airstream, mixing, or exhaust properties), and thereby the aforementioned exemplary percent contribution to total thrust, may passively adjust during engine operation or be modified purposefully through use of engine control features (such as fuel flow, electric machine power, variable stators, variable inlet guide vanes, valves, variable exhaust geometry, or fluidic features) to adjust or optimize overall system performance across a broad range of potential operating conditions.

Certain modern fan blades are formed of composite material(s) to reduce a weight of the fan blades. However, aircraft engine components, such as fan blades, nacelles, guide vanes, etc., used in jet engine applications are susceptible to foreign object impact damage or ingestion events, such as an ice ingestion or bird strike. Moreover, fan blades formed from composite material(s) may be more susceptible to damage in such events, e.g., by blade fracture, component delamination, bending or deformation damage, or other forms of blade damage. Accordingly, improved airfoil designs for addressing one or more of the above-mentioned problems would be useful. More specifically, an airfoil assembly with a lightweight and structurally sound design that can withstand foreign object ingestion events would be particularly beneficial.

Accordingly, aspects of the present subject matter are directed to an airfoil assembly and methods of manufacturing the same for improved blade performance, durability, etc. For example, the airfoil assembly may include a reinforcement structure that includes two or more helical support structures that wrap around a span axis of the airfoil assembly. These helical support structures may be concentric and may be formed to have different wire sizes, different materials, different helix pitches, etc. In addition, the reinforcement structure may include a plurality of struts mechanically coupling the first helical support structure and the second helical support structure and a polymeric matrix material positioned at least partially around the reinforcement structure. An outer skin may be positioned around the reinforcement structure and the polymeric matrix material to form the airfoil assembly.

Such a composite blade construction may facilitate improved blade durability, thus enabling fan blade weight reduction while minimizing the potential for blade deformation, debonding, failure, or other operational degradation. In addition, local blade stiffnesses may be modified and tailored by selectively designing and positioning the various helixes, connector struts, or other portions of the reinforcement structure. Moreover, such constructions may improve fan blade stability to meet aeromechanical requirements, may result in an improvement in dissipation of shock wave energy due to impact loads, may provide better control of blade untwist behavior to improve the operability margins, may improve fan blade durability, etc.

Referring now to FIG. **1**, a schematic cross-sectional view of a gas turbine engine **100** is provided according to an example embodiment of the present disclosure. Particularly, FIG. **1** provides an engine having a rotor assembly with a single stage of unducted rotor blades. In such a manner, the rotor assembly may be referred to herein as an “unducted fan,” or the entire gas turbine engine **100** may be referred to as an “unducted engine,” or an engine having an open rotor propulsion system **102**. In addition, the engine of FIG. **1** includes a mid-fan stream extending from the compressor section to a rotor assembly flowpath over the turbomachine, as will be explained in more detail below. It is also contemplated that, in other exemplary embodiments, the present disclosure is compatible with an engine having a duct around the unducted fan. It is also contemplated that, in other exemplary embodiments, the present disclosure is compatible with a turbofan engine having a third stream as described herein.

For reference, the gas turbine engine **100** defines an axial direction A, a radial direction R, and a circumferential direction C. Moreover, the gas turbine engine **100** defines an axial centerline or longitudinal axis **112** that extends along the axial direction A. In general, the axial direction A extends parallel to the longitudinal axis **112**, the radial direction R extends outward from and inward to the longitudinal axis **112** in a direction orthogonal to the axial direction A, and the circumferential direction extends three hundred sixty degrees (360°) around the longitudinal axis **112**. The gas turbine engine **100** extends between a forward end **114** and an aft end **116**, e.g., along the axial direction A.

The gas turbine engine **100** includes a turbomachine **120**, also referred to as a core of the gas turbine engine **100**, and a rotor assembly, also referred to as a fan section **150**, positioned upstream thereof. Generally, the turbomachine **120** includes, in serial flow order, a compressor section, a combustion section, a turbine section, and an exhaust section. Particularly, as shown in FIG. **1**, the turbomachine **120** includes a core cowl **122** that defines an annular core inlet **124**. The core cowl **122** further encloses at least in part a low pressure system and a high pressure system. For example, the core cowl **122** depicted encloses and supports at least in part a booster or low pressure ("LP") compressor **126** for pressurizing the air that enters the turbomachine **120** through core inlet **124**. A high pressure ("HP"), multi-stage, axial-flow compressor **128** receives pressurized air from the LP compressor **126** and further increases the pressure of the air. The pressurized air stream flows downstream to a combustor **130** of the combustion section where fuel is injected into the pressurized air stream and ignited to raise the temperature and energy level of the pressurized air and produce high energy combustion products.

It will be appreciated that as used herein, the terms "high/low speed" and "high/low pressure" are used with respect to the high pressure/high speed system and low pressure/low speed system interchangeably. Further, it will be appreciated that the terms "high" and "low" are used in this same context to distinguish the two systems, and are not meant to imply any absolute speed and/or pressure values.

The high energy combustion products flow from the combustor **130** downstream to a high pressure turbine **132**. The high pressure turbine **132** drives the high pressure compressor **128** through a high pressure shaft **136**. In this regard, the high pressure turbine **132** is drivingly coupled with the high pressure compressor **128**. The high energy combustion products then flow to a low pressure turbine **134**. The low pressure turbine **134** drives the low pressure compressor **126** and components of the fan section **150** through a low pressure shaft **138**. In this regard, the low pressure turbine **134** is drivingly coupled with the low pressure compressor **126** and components of the fan section **150**. The LP shaft **138** is coaxial with the HP shaft **136** in this example embodiment. After driving each of the turbines **132**, **134**, the combustion products exit the turbomachine **120** through a core or turbomachine exhaust nozzle **140**.

Accordingly, the turbomachine **120** defines a working gas flowpath **142** that extends between the core inlet **124** and the turbomachine exhaust nozzle **140**. The working gas flowpath **142** is an annular flowpath positioned generally inward of the core cowl **122** along the radial direction R and extends through the turbomachine **120**. The working gas flowpath **142** may also be referred to herein as a second stream.

The fan section **150** includes a fan **152**, which is the primary fan in this example embodiment. For the depicted embodiment of FIG. **1**, the fan **152** is an open rotor or unducted fan **152**. As depicted, the fan **152** includes an array of fan blades **154** (only one shown in FIG. **1**). The fan blades **154** are rotatable, e.g., about the longitudinal axis **112**. As noted above, the fan **152** is drivingly coupled with the low pressure turbine **134** via the LP shaft **138**. The fan **152** can be directly coupled with the LP shaft **138**, e.g., in a direct-drive configuration. However, for the embodiments shown in FIG. **1**, the fan **152** is coupled with the LP shaft **138** via a speed reduction gearbox **155**, e.g., in an indirect-drive or geared-drive configuration.

Moreover, the fan blades **154** can be arranged in equal spacing around the longitudinal axis **112**. Each fan blade **154** has a root and a tip and a span defined therebetween. Each fan blade **154** defines a central blade axis **156**. For this embodiment, each fan blade **154** of the fan **152** is rotatable about their respective central blade axis **156**, e.g., in unison with one another. One or more actuators **158** are provided to facilitate such rotation and therefore may be used to change a pitch the fan blades **154** about their respective central blade axis **156**.

The fan section **150** further includes a fan guide vane array **160** that includes fan guide vanes **162** (only one shown in FIG. **1**) disposed around the longitudinal axis **112**. For this embodiment, the fan guide vanes **162** are not rotatable about the longitudinal axis **112**. Each fan guide vane **162** has a root and a tip and a span defined therebetween. The fan guide vanes **162** may be unshrouded as shown in FIG. **1** or, alternatively, may be shrouded, e.g., by an annular shroud spaced outward from the tips of the fan guide vanes **162** along the radial direction R or attached to the fan guide vanes **162**.

Each fan guide vane **162** defines a central blade axis **164**. For this embodiment, each fan guide vane **162** of the fan guide vane array **160** is rotatable about their respective central blade axis **164**, e.g., in unison with one another. One or more actuators **166** are provided to facilitate such rotation and therefore may be used to change a pitch of the fan guide vane **162** about their respective central blade axis **164**. However, in other embodiments, each fan guide vane **162** may be fixed or unable to be pitched about its central blade axis **164**. The fan guide vanes **162** are mounted to a fan cowl **170**.

As shown in FIG. **1**, in addition to the fan **152**, which is unducted, a ducted fan **184** is included aft of the fan **152**, such that the gas turbine engine **100** includes both a ducted and an unducted fan which both serve to generate thrust through the movement of air without passage through at least a portion of the turbomachine **120** (e.g., the HP compressor **128** and combustion section for the embodiment depicted). The ducted fan **184** is shown at about the same axial location as the fan blade **154**, and radially inward of the fan blade **154**. The ducted fan **184**, for the embodiment depicted, is driven by the low pressure turbine **134** (e.g., coupled to the LP shaft **138**).

The fan cowl **170** annularly encases at least a portion of the core cowl **122** and is generally positioned outward of at least a portion of the core cowl **122** along the radial direction R. Particularly, a downstream section of the fan cowl **170** extends over a forward portion of the core cowl **122** to define a fan flowpath **172**. The fan flowpath **172** may be referred to as a third stream of the gas turbine engine **100**.

Incoming air may enter through the fan flowpath **172** through a fan duct inlet **176** and may exit through a fan exhaust nozzle **178** to produce propulsive thrust. The fan flowpath **172** is an annular duct positioned generally outward of the working gas flowpath **142** along the radial direction R. The fan cowl **170** and the core cowl **122** are connected together and supported by a plurality of substantially radially-extending, circumferentially-spaced stationary struts **174** (only one shown in FIG. **1**). The stationary struts **174** may each be aerodynamically contoured to direct air flowing thereby. Other struts in addition to the stationary struts **174** may be used to connect and support the fan cowl **170** and/or core cowl **122**. In many embodiments, the fan flowpath **172** and the working gas flowpath **142** may at least partially co-extend (generally axially) on opposite sides (e.g., opposite radial sides) of the core cowl **122**. For example, the fan flowpath **172** and the working gas flowpath **142** may each extend directly from a leading edge **144** of the core cowl **122** and may partially co-extend generally axially on opposite radial sides of the core cowl.

The gas turbine engine **100** also defines or includes an inlet duct **180**. The inlet duct **180** extends between an engine inlet **182** and the core inlet **124**/fan duct inlet **176**. The engine inlet **182** is defined generally at the forward end of the fan cowl **170** and is positioned between the fan **152** and the fan guide vane array **160** along the axial direction A. The inlet duct **180** is an annular duct that is positioned inward of the fan cowl **170** along the radial direction R. Air flowing downstream along the inlet duct **180** is split, not necessarily evenly, into the working gas flowpath **142** and the fan flowpath **172** by a splitter or leading edge **144** of the core cowl **122**. The inlet duct **180** is wider than the working gas flowpath **142** along the radial direction R. The inlet duct **180** is also wider than the fan flowpath **172** along the radial direction R.

Referring now generally to FIGS. **2** through **6**, airfoil assemblies **200** that may be used in a gas turbine engine will be described according to exemplary embodiments of the present subject matter. Specifically, FIGS. **2** through **5** provide schematic illustrations of an airfoil assembly **200** including reinforcement structure that may be used in gas turbine engine **100**, e.g., as fan blade **154** or as fan guide vanes **162**. In addition, FIG. **6** provides another exemplary configuration of an airfoil assembly **290**, e.g., similar to that which may be used in gas turbine engine **100**, e.g., where a central spar includes reinforcement structure, as described in more detail below.

Notably, due to the similarity between embodiments described herein, like reference numerals may be used to refer to the same or similar features among various embodiments. Although airfoil assemblies **200** are described herein as being used with gas turbine engine **100**, it should be appreciated that aspects of the present subject matter may be applicable to any suitable blades for any suitable gas turbine engine. Indeed, the exemplary blade constructions and features described herein may be interchangeable among embodiments to generate additional exemplary embodiments. The specific structures illustrated and described herein are only exemplary and are not intended to limit the scope of the present subject matter in any manner.

Referring now specifically to FIGS. **2** through **5**, airfoil assembly **200** will be described according to an exemplary embodiment. Notably, it should be appreciated that these drawings may not illustrate all features of airfoil assembly **200** to simplify discussion and clarity of aspects of the present subject matter. For example, as described in more detail below with respect to FIG. **6**, airfoil assembly **290** may include various attachment structures, fillers, support structures, etc.

In general, airfoil assembly **200** defines a root end **202** and may extend outward from root end **202** along the radial direction R toward a tip end **204** of airfoil assembly **200**, e.g., along a span **206** of airfoil assembly **200**. In this regard, span **206** of airfoil assembly **200** may be generally defined as the distance between root end **202** and tip end **204** of airfoil assembly **200** as measured along the radial direction R. In addition, the term "span axis" (identified generally by reference numeral **208**) may generally refer to a line or axis that extends through a geometrical center of airfoil assembly **200** at each cross-section taken perpendicular to the radial direction R.

In addition, airfoil assembly **200** includes a reinforcement structure **210** and a blade skin **212** that is generally positioned on or wrapped around reinforcement structure **210** to define an airfoil **214** (e.g., the outer profile of a fan blade or airfoil). Blade skin **212** may be a polymer matrix composite (PMC), epoxy resin, carbon fiber, glass fiber, thermoplastics material, etc. As used herein, the terms "airfoil" and the like may generally refer to the shape or geometry of an outer surface of airfoil assembly **200**, e.g., the surface that interacts with the stream of air passing over airfoil assembly **200**. In general, airfoil **214** has a suction side **216** and a pressure side **218** extending in the axial direction A between a leading edge **220** (e.g., a forward end of airfoil **214**) and a trailing edge **222** (e.g., an aft end of airfoil **214**). In addition, a chord line **224** may be generally defined as a line extending between leading edge **220** and trailing edge **222**, and the term "chordwise direction" may generally refer to the relative position along chord line **224**.

Reinforcement structure **210** will now be described in more detail according to exemplary embodiments of the present subject matter. In general, reinforcement structure **210** may generally include one or more helical support structures. For example, according to the illustrated embodiment, reinforcement structure **210** includes a first helical support structure **230** and a second helical support structure **232**, each of which wrap around span axis **208** and extend at least partially between root end **202** and tip end **204** of airfoil assembly **200**. As will be explained in more detail below, first helical support structure **230** and second helical support structure **232** may generally provide the primary structural support for airfoil **214** and may generally define the profile of airfoil **214**.

As used herein, the term "helical" may be used to generally describe the geometry of first helical support structure **230** and second helical support structure **232**. However, it should be appreciated that the present disclosure does not require a perfectly helical structure or a structure that forms a circular cross section. In this regard, the term "helical" may be used generally to refer to any spiral, corkscrew, or similar geometry, e.g., such as any curve that is wrapped around span axis **208** and which would form a straight line or continuous wire if it was unrolled into a single plane. In addition, according to the embodiments illustrated in FIGS. **2** through **6**, span axis **208** is illustrated as being substantially straight, but it should be appreciated that span axis **208** may have any suitable curved profile that follows a center of a cross-section of airfoil assembly **200**.

Notably, the size, geometry, and orientation of first helical support structure **230** and second helical support structure **232** may be varied as needed to provide airfoil assembly **200** with the desired structural characteristics. In this regard, according to the illustrated embodiment, first helical support structure **230** and second helical support structure **232** are concentric, e.g., sharing a common center which may correspond to span axis **208**. In addition, second helical support structure **232** is illustrated as having a smaller footprint and being positioned inside of first helical support structure **230**, though other support configurations are possible and within the scope of the present subject matter.

In addition, first helical support structure **230** and second helical support structure **232** may be wrapped in different directions about span axis **208**. For example, according to the illustrated embodiment, first helical support structure **230** may be wrapped in a clockwise direction around span axis **208**, e.g., when looking down span axis **208** from tip end **204** and toward root end **202**. By contrast, second helical support structure **232** may be wrapped in a counterclockwise direction around span axis **208**, e.g., when looking down span axis **208** from tip end **204** and toward root end **202**. According to alternative embodiments, first helical support structure **230** and second helical support structure **232** may be wrapped in the same direction (e.g., both being wrapped in the clockwise direction).

According to the illustrated embodiment, each of first helical support structure **230** and second helical support structure **232** may be formed from a single elongated piece of wire that is wrapped about span axis **208** in a helical fashion. According to exemplary embodiments, first helical support structure **230** may generally define a first wire diameter **234** and second helical support structure **232** may generally define a second wire diameter **236**. It should be appreciated that using the manufacturing techniques described herein, first wire diameter **234** and second wire diameter **236** may be varied as needed throughout reinforcement structure **210** to achieve the desired performance and structural characteristics of airfoil assembly **200**. For example, at least one of first wire diameter **234** or second wire diameter **236** may vary along span axis **208**. In addition, it should be appreciated that first wire diameter **234** and second wire diameter **236** may be different at any given spanwise location along reinforcement structure **210**.

In addition, according to the illustrated embodiment, first helical support structure **230** may generally define a first helix pitch **238** and second helical support structure **232** may define a second helix pitch **240**. According to exemplary embodiments, the helix pitches **238**, **240** may be varied as needed depending on the application. For example, according to an exemplary embodiment, at least one of first helix pitch **238** or second helix pitch **240** may vary along span axis **208**. In this regard, for example, the helix pitches **238**, **240** may be smaller where higher blade stresses are experienced and larger where lower blade stresses are experienced.

Referring still generally to FIGS. **2** through **5**, reinforcement structure **210** may further include a plurality of struts **250** for mechanically coupling first helical support structure **230** to second helical support structure **232**. In this regard, struts **250** are generally structural or mechanical support members that extend between various portions of the helical support structures to improved rigidity, transmit forces, etc. Although exemplary struts **250** are described herein for the example embodiment showing first helical support structure **230** and second helical support structure **232**, it should be appreciated that the number, size, and configuration of struts **250** may be varied as needed depending on the application. According to the illustrated embodiment, struts **250** are straight members that extend between two points on helical support structures, though struts could take any other shape according to alternative embodiments.

As shown, the plurality of struts **250** may generally include a plurality of turn connectors **252** that extend between and mechanically couple adjacent turns or passes of a respective helical support structure. In this regard, turn connectors **252** are illustrated on the left side of FIGS. **2**, **4**, and **5** as connecting adjacent portions of respective helical support structures. In this regard, for example, a first set of turn connectors **252** are illustrated as extending substantially along the radial direction R to couple adjacent passes of first helical support structure **230**. Notably, this connection may also help to stabilize or fix the first helix pitch **238**. As illustrated, second helical support structure **232** may include similar turn connectors **252**.

In addition, according to exemplary embodiments, the plurality of struts **250** may also include a plurality of helix connectors **254** that extend between and mechanically couple two or more helical support structures. In this regard, as best illustrated on the right side of FIGS. **2**, **4**, and **5**, helix connectors **254** may pass substantially along the radial direction R to connect portions, passes, or turns of first helical support structure **230** and second helical support structure **232** that are adjacent to each other.

Although struts **250** are generally illustrated as connecting adjacent portions of first helical support structure **230** and/or second helical support structure **232**, it should be appreciated that reinforcement structure **210** may include struts **250** that connect any other suitable portions or regions of the one or more helical support structures for improving the rigidity or blade performance. In this regard, for example, struts **250** may extend in a direction other than the radial direction R or the spanwise direction, e.g., as illustrated for example in the foreground of FIG. **4**. According to still other embodiments, struts **250** may be designed to extend along a chordwise direction or along the chord line **224** of airfoil **214**. Furthermore, it should be appreciated that the size, thickness, geometry, and spacing of struts **250** may be varied as needed depending on the application. For example, struts **250** may be spaced about a perimeter of first helical support structure **230** and second helical support structure **232**.

In general, reinforcement structure **210** and all components therein may be manufactured in any suitable manner in from any suitable materials. For example, first helical support structure **230**, second helical support structure **232**, and/or struts **250** may include at least one of metal, metal fibers, shape-memory alloys, carbon materials, aramids, functionally graded materials (FGMs), or carbon nano fibers. In addition, it should be appreciated that portions of reinforcement structure **210** may be formed from different materials. In this regard, first helical support structure **230** may be formed from a different material than second helical support structure **232**, which may be different than struts **250**, etc.

In addition, any suitable manufacturing method may be used for manufacturing reinforcement structure **210**. For example, each helical support structure **230**, **232** may be separately formed and struts **250** may be mechanically fastened, welded, or otherwise joined to solidify reinforcement structure **210**. According to still other embodiments, reinforcement structure **210** may be additively manufactured as a single, integral piece. As used herein, the terms "additively manufactured" or "additive manufacturing techniques or processes" refer generally to manufacturing processes wherein successive layers of material(s) are provided on each other to "build-up," layer-by-layer, a three-dimensional component. The successive layers generally fuse together to form a monolithic component which may have a variety of integral sub-components.

Suitable additive manufacturing techniques in accordance with the present disclosure include, for example, Fused Deposition Modeling (FDM), Selective Laser Sintering (SLS), 3D printing such as by inkjets and laserjets, Stereolithography (SLA), Direct Selective Laser Sintering (DSLS), Electron Beam Sintering (EBS), Electron Beam Melting (EBM), Laser Engineered Net Shaping (LENS), Laser Net Shape Manufacturing (LNSM), Direct Metal Deposition (DMD), Digital Light Processing (DLP), Direct Selective Laser Melting (DSLM), Selective Laser Melting (SLM), Direct Metal Laser Melting (DMLM), and other known processes.

In addition to using a direct metal laser sintering (DMLS) or direct metal laser melting (DMLM) process where an energy source is used to selectively sinter or melt portions of a layer of powder, it should be appreciated that according to alternative embodiments, the additive manufacturing process may be a "binder jetting" process. In this regard, binder jetting involves successively depositing layers of additive powder in a similar manner as described above. However, instead of using an energy source to generate an energy beam to selectively melt or fuse the additive powders, binder jetting involves selectively depositing a liquid binding agent onto each layer of powder. The liquid binding agent may be, for example, a photo-curable polymer or another liquid bonding agent. Other suitable additive manufacturing methods and variants are intended to be within the scope of the present subject matter.

The additive manufacturing processes described herein may be used for forming components using any suitable material. For example, the material may be plastic, metal, concrete, ceramic, polymer, epoxy, photopolymer resin, or any other suitable material that may be in solid, liquid, powder, sheet material, wire, or any other suitable form. More specifically, according to exemplary embodiments of the present subject matter, the additively manufactured components described herein may be formed in part, in whole, or in some combination of materials including but not limited to plastics, pure metals, metal alloys (e.g., such as nickel, chrome, titanium, iron, stainless steel, etc.), epoxy, composites, or any other suitable polymer, ceramic, or metal materials. These materials are examples of materials suitable for use in the additive manufacturing processes described herein and may be generally referred to as "additive materials."

In addition, one skilled in the art will appreciate that a variety of materials and methods for bonding those materials may be used and are contemplated as within the scope of the present disclosure. As used herein, references to "fusing" may refer to any suitable process for creating a bonded layer of any of the above materials. For example, if an object is made from polymer, fusing may refer to creating a thermoset bond between polymer materials. If the object is epoxy, the bond may be formed by a crosslinking process. If the material is ceramic, the bond may be formed by a sintering process. If the material is powdered metal, the bond may be formed by a melting or sintering process. One skilled in the art will appreciate that other methods of fusing materials to make a component by additive manufacturing are possible, and the presently disclosed subject matter may be practiced with those methods.

In addition, the additive manufacturing process disclosed herein allows a single component to be formed from multiple materials. Thus, the components described herein may be formed from any suitable mixtures of the above materials. For example, a component may include multiple layers, segments, or parts that are formed using different materials, processes, and/or on different additive manufacturing machines. In this manner, components may be constructed which have different materials and material properties for meeting the demands of any particular application. In addition, although the components described herein are constructed entirely by additive manufacturing processes, it should be appreciated that in alternate embodiments, all or a portion of these components may be formed via casting, machining, and/or any other suitable manufacturing process. Indeed, any suitable combination of materials and manufacturing methods may be used to form these components.

According to exemplary embodiments of the present subject matter, airfoil assembly **200** may further include a polymeric matrix material **260** that is positioned at least partially around reinforcement structure **210**. In general, polymeric matrix material **260** may be generally configured for solidifying or binding together various components of reinforcement structure **210** also providing a bond between reinforcement structure **210** and blade skin **212**. Polymeric matrix material **260** may be generally formed from any suitable material and may be applied to reinforcement structure **210** in any suitable manner. Blade skin **212** may be wrapped around or positioned on an outer surface of reinforcement structure **210** and/or polymeric matrix material **260**. According to exemplary embodiments the present subject matter, polymeric matrix material **260** may fully enclose or encapsulate reinforcement structure **210** and provide a uniform structure or surface for receiving blade skin **212**.

In general, polymeric matrix material **260** may include any suitable number, type, and combination of materials that serve to bond or join together portions of reinforcement structure **210** and/or blade skin **212**. For example, polymeric matrix material **260** may include a polymer slurry with one or more structural reinforcement fibers embedded therein for improved rigidity. In addition, it should be appreciated that according to exemplary embodiments, polymeric matrix material **260** may include or be coated with one or more adhesives for improved engagement with reinforcement structure **210** and/or blade skin **212**. For example, adhesives may include epoxy, polyurethane, or any other kind adhesive known to those of ordinary skill in the art. In addition, according to example embodiments, polymeric matrix material **260** may include a stronger particulate at leading edge **220** to provide impact resistance.

According to the illustrated embodiment, airfoil assembly **200** may further generally define one or more inner cavities **264**. According to exemplary embodiments, the one or more inner cavities **264** may be filled with a foam **266** and may be generally configured for improving the rigidity without unnecessarily increasing a weight of airfoil assembly **200**. According to exemplary embodiments, foam **266** may generally include at least one of polymethacrylimide (PMI) foam or a urethane foam. In addition, or alternatively, foam **266** may also include cast syntactic or expanding syntactic foams, e.g., glass, carbon, or phenolic micro balloons cast in resin. Other suitable foams are possible and within the scope of the present subject matter. According to exemplary embodiments, foam **266** may include any suitable number and type of foam reinforcement structures.

Notably, in the embodiment illustrated in FIGS. **2** through **5**, airfoil assembly **200** includes reinforcement structure **210**, polymeric matrix material **260**, blade skin **212**, and foam **266** filling the one or more inner cavities **264** of airfoil assembly **200**. In this manner, airfoil assembly **200** generally represents the complete airfoil, such as fan blades **154** and/or fan guide vanes **162**. However, according to alternative embodiments, these constructions may be used to form other portions of airfoil assembly **200**. For example, as described in more detail below and as illustrated in FIG. **6**, an airfoil assembly **290** is provided including a similar construction using reinforcement structure **210** polymeric matrix material **260**, and an outer skin **280** may be used to form a central spar **282** of an airfoil assembly **200**.

In this regard, as shown in FIG. **6**, airfoil **290** may include a central spar **282** that extends outward along a radial direction R, e.g., which corresponds to radial direction R when airfoil assembly **290** is installed in gas turbine engine **100**. More specifically, as illustrated, central spar **282** may include a blade attachment structure **284**, e.g., illustrated as a dovetail, for securing airfoil assembly **290** to a rotating central hub (e.g., or mechanically coupling airfoil assemblies **290** to actuators **158**). Notably, conventional central spars are formed from solid, rigid material in order to withstand the forces exerted on airfoil assembly **290** during operation of the gas turbine engine **100**. However, the composite structure described above may be used to form a sufficiently lightweight and rigid central spar **282** and/or the remainder of airfoil assembly **290**.

In this regard, as illustrated, first helical support structure **230** and second helical support structure **232** may be positioned within outer skin **280** to define an outer boundary of central spar **282**. It should be appreciated that first helical support structure **230** and second helical support structure **232** may be formed to create central spar **282** having any suitable size, shape, geometry, etc. In addition, polymeric matrix material **260** may be positioned around or encapsulate first helical support structure **230** and second helical support structure **232**. Outer skin **280** (e.g., which may be similar to the blade skin **212**) may be wrapped around first helical support structure **230** and second helical support structure **232** to define an outer boundary of central spar **282**. As used herein, the terms "outer skin" and the like may be used to refer to blade skin **212** (e.g., when reinforcement structure **210** is used to form airfoil **214**) or outer skin **280** (e.g., when reinforcement structure **210** is used to form central spar **282**). According to exemplary embodiments, airfoil **214** may be formed in the same manner as described above and may be attached to a central spar **282** in any suitable manner to complete the formation of airfoil assembly **290**.

Referring now to FIG. **7**, an exemplary method **300** for constructing an airfoil assembly will be described according to exemplary embodiments of the present subject matter. For example, method **300** may be used to construct airfoil assembly **200** as described above. However, it should be appreciated that aspects of method **300** may be applied to the construction of any other suitable airfoil. In addition, it should be appreciated that alterations and modifications may be made to method **300** while remaining within scope of the present subject matter.

Method **300** may include, at step **310**, laying up a reinforcement structure comprising a first helical support structure wrapping around a span axis of the airfoil assembly between a root end and a tip end and the second helical support structure wrapping around the span axis between the root end and the tip end. In this regard, continuing the example above, step **310** may include forming reinforcement structure **210** using first helical support structure **230** and second helical support structure **232**. Step **320** may include mechanically coupling the first helical support structure and the second helical support structure with a plurality of struts. As explained above these struts may include turn connectors and/or helix connectors. It should be appreciated that the reinforcement structure described above may be manufactured in any suitable manner, such as via additive manufacturing.

Step **330** may generally include applying a polymeric matrix material at least partially surrounded reinforcement structure and step **340** may include positioning an outer skin around the reinforcement structure and polymer matrix material to form the airfoil assembly (or central spar). As explained above, steps **310** through **340** may be used to form all or any portion of airfoil assembly **200**. For example, reinforcement structure **210**, polymeric matrix material **260**, and outer skin **280** may be used to form a central spar **282** of airfoil assembly **200**. In addition, or alternatively, reinforcement structure **210**, polymeric matrix material **260**, and blade skin **212** may be used to form airfoil **214** of airfoil assembly **200**.

In general, method **300** may include additional steps for improving the rigidity or performance of the airfoil assembly. For example, method **300** may include applying an adhesive at one or more stages of the manufacturing process, may include the formation of any other suitable number of helical support structures or support struts, etc. Other variations and modifications to airfoil assembly **200** and to method **300** of forming airfoil assembly **200** are possible and within the scope of the present subject matter.

FIG. **7** depicts steps performed in a particular order for purposes of illustration and discussion. Those of ordinary skill in the art, using the disclosures provided herein, will understand that the steps of any of the methods discussed herein can be adapted, rearranged, expanded, omitted, or modified in various ways without deviating from the scope of the present disclosure. Moreover, although aspects of method **300** are explained using airfoil assembly **200** as an example, it should be appreciated that this method may be applied to the construction of any other suitable airfoil for any other suitable application.

Further aspects are provided by the subject matter of the following clauses:

An airfoil assembly defining a span axis, a root end, and a tip end, the airfoil assembly comprising: a reinforcement structure comprising a first helical support structure wrapped around the span axis between the root end and the tip end and a second helical support structure wrapped around the span axis between the root end and the tip end; a polymeric matrix material positioned at least partially around the reinforcement structure; and an outer skin positioned around the reinforcement structure and the polymeric matrix material.

The airfoil assembly of any preceding clause, wherein the reinforcement structure further comprises: a plurality of struts mechanically coupling the first helical support structure to the second helical support structure.

The airfoil assembly of any preceding clause, wherein the plurality of struts comprises: a plurality of turn connectors that extend between and mechanically couple adjacent turns of the first helical support structure or the second helical support structure.

The airfoil assembly of any preceding clause, wherein the plurality of struts comprises: a plurality of helix connectors that extend between and mechanically couple the first helical support structure to the second helical support structure.

The airfoil assembly of any preceding clause, wherein the plurality of struts extends substantially along the span axis or substantially along a chordwise direction.

The airfoil assembly of any preceding clause, wherein the plurality of struts are spaced about a perimeter of the first helical support structure and the second helical support structure.

The airfoil assembly of any preceding clause, wherein the first helical support structure defines a first wire diameter and the second helical support structure defines a second wire diameter, and wherein at least one of the first wire diameter or the second wire diameter varies along the span axis.

The airfoil assembly of any preceding clause, wherein the first helical support structure defines a first helix pitch and the second helical support structure defines a second helix pitch, and wherein at least one of the first helix pitch or the second helix pitch varies along the span axis.

The airfoil assembly of any preceding clause, wherein the first helical support structure wraps clockwise around the span axis and the second helical support structure wraps counterclockwise around the span axis.

The airfoil assembly of any preceding clause, wherein the first helical support structure and the second helical support structure are concentric.

The airfoil assembly of any preceding clause, wherein the polymeric matrix material encapsulates the reinforcement structure and bonds the reinforcement structure to the outer skin.

The airfoil assembly of any preceding clause, wherein the first helical support structure and the second helical support structure comprise at least one of metal, metal fibers, shape-memory alloys, carbon materials, aramids, functionally graded materials (FGMs), or carbon nano fibers.

The airfoil assembly of any preceding clause, wherein the first helical support structure and the second helical support structure are formed from different materials.

The airfoil assembly of any preceding clause, wherein the first helical support structure and the second helical support structure are additively manufactured as a single, integral piece.

The airfoil assembly of any preceding clause, wherein the reinforcement structure, the polymeric matrix material, and the outer skin form a central spar of the airfoil assembly.

The airfoil assembly of any preceding clause, wherein the outer skin is a blade skin that defines an airfoil that has a pressure side and a suction side.

The airfoil assembly of any preceding clause, wherein the reinforcement structure defines an inner cavity, and wherein the airfoil assembly further comprises: a foam filling the inner cavity, the foam comprising at least one of a polymethacrylimide (PMI) foam, a urethane foam, or a cast syntactic foam.

A method of manufacturing an airfoil assembly, the airfoil assembly defining a span axis, a root end, and a tip end, the method comprising: laying up a reinforcement structure comprising a first helical support structure wrapped around the span axis between the root end and the tip end and a second helical support structure wrapped around the span axis between the root end and the tip end; applying a polymeric matrix material at least partially around the reinforcement structure; and positioning an outer skin around the reinforcement structure and the polymeric matrix material to form the airfoil assembly.

The method of any preceding clause, further comprising: mechanically coupling the first helical support structure and the second helical support structure with a plurality of struts.

The method of any preceding clause, wherein the first helical support structure and the second helical support structure are additively manufactured as a single, integral piece

This written description uses examples to disclose the present disclosure, including the best mode, and also to enable any person skilled in the art to practice the disclosure, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the disclosure is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they include structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

We claim:

1. An airfoil assembly defining a span axis, a root end, and a tip end, the airfoil assembly comprising:

a reinforcement structure comprising a first helical support structure fully wrapped around the span axis between the root end and the tip end and a second helical support structure fully wrapped around the span axis between the root end and the tip end, wherein the first helical support structure defines a first wire diameter and the second helical support structure defines a second wire diameter, and wherein at least one of the first wire diameter or the second wire diameter varies along the span axis;

a polymeric matrix material positioned at least partially around the reinforcement structure; and

an outer skin positioned around the reinforcement structure and the polymeric matrix material.

2. The airfoil assembly of claim **1**, wherein the reinforcement structure further comprises:

a plurality of struts mechanically coupling the first helical support structure to the second helical support structure.

3. The airfoil assembly of claim **2**, wherein the plurality of struts comprises:

a plurality of turn connectors that extend between and mechanically couple adjacent turns of the first helical support structure or the second helical support structure.

4. The airfoil assembly of claim **2**, wherein the plurality of struts comprises:

a plurality of helix connectors that extend between and mechanically couple the first helical support structure to the second helical support structure.

5. The airfoil assembly of claim **2**, wherein the plurality of struts extends substantially along the span axis or substantially along a chordwise direction.

6. The airfoil assembly of claim **2**, wherein the plurality of struts are spaced about a perimeter of the first helical support structure and the second helical support structure.

7. The airfoil assembly of claim **1**, wherein the first helical support structure defines a first helix pitch and the second helical support structure defines a second helix pitch, and wherein at least one of the first helix pitch or the second helix pitch varies along the span axis.

8. The airfoil assembly of claim **1**, wherein the first helical support structure wraps clockwise around the span axis and the second helical support structure wraps counterclockwise around the span axis.

9. The airfoil assembly of claim **1**, wherein the first helical support structure and the second helical support structure are concentric.

10. The airfoil assembly of claim **1**, wherein the polymeric matrix material encapsulates the reinforcement structure and bonds the reinforcement structure to the outer skin.

11. The airfoil assembly of claim **1**, wherein the first helical support structure and the second helical support structure comprise at least one of metal, metal fibers, shape-memory alloys, carbon materials, aramids, functionally graded materials (FGMs), or carbon nano fibers.

12. The airfoil assembly of claim **1**, wherein the first helical support structure and the second helical support structure are formed from different materials.

13. The airfoil assembly of claim **1**, wherein the first helical support structure and the second helical support structure are additively manufactured as a single, integral piece.

14. The airfoil assembly of claim **1**, wherein the reinforcement structure, the polymeric matrix material, and the outer skin form a central spar of the airfoil assembly.

15. The airfoil assembly of claim **1**, wherein the reinforcement structure defines an inner cavity, and wherein the airfoil assembly further comprises:

a foam filling the inner cavity, the foam comprising at least one of a polymethacrylimide (PMI) foam, a urethane foam, or a cast syntactic foam.

16. A method of manufacturing an airfoil assembly, the airfoil assembly defining a span axis, a root end, and a tip end, the method comprising:

laying up a reinforcement structure comprising a first helical support structure fully wrapped around the span axis between the root end and the tip end and a second helical support structure fully wrapped around the span axis between the root end and the tip end, wherein the first helical support structure wraps clockwise around the span axis and the second helical support structure wraps counterclockwise around the span axis;

applying a polymeric matrix material at least partially around the reinforcement structure; and

positioning an outer skin around the reinforcement structure and the polymeric matrix material to form the airfoil assembly.

17. The method of claim **16**, further comprising:

mechanically coupling the first helical support structure to the second helical support structure with a plurality of struts.

18. The method of claim **16**, wherein the first helical support structure and the second helical support structure are additively manufactured as a single, integral piece.

19. An airfoil assembly defining a span axis, a root end, and a tip end, the airfoil assembly comprising:

a reinforcement structure comprising a first helical support structure wrapped around the span axis between the root end and the tip end and a second helical support structure wrapped around the span axis between the root end and the tip end, the reinforcement structure further comprising a plurality of struts mechanically coupling the first helical support structure to the second helical support structure, the plurality of struts comprising a plurality of turn connectors that extend between and mechanically couple adjacent turns of the first helical support structure or the second helical support structure;

a polymeric matrix material positioned at least partially around the reinforcement structure; and

an outer skin positioned around the reinforcement structure and the polymeric matrix material.

20. The airfoil assembly of claim **19**, wherein the first helical support structure and the second helical support structure are formed from different materials.

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